DESCRIPTION

ONE-PORT SURFACE ACOUSTIC WAVE RESONATOR AND SURFACE ACOUSTIC WAVE FILTER

Technical Field

The present invention relates to one-port surface acoustic wave resonators having reflectors at both sides of an interdigital electrode transducer and relates to surface acoustic wave filters using the one-port surface acoustic wave resonators. More specifically, the present invention relates to one-port surface acoustic wave resonators and surface acoustic wave filters which use a rotated Y-cut $LiTaO_3$ substrate as a piezoelectric substrate.

Background Art

A variety of one-port surface acoustic wave resonators using a rotated Y-cut X-propagation $LiTaO_3$ substrate have heretofore been proposed to constitute bandpass filters for communication devices. The one-port surface acoustic wave resonator includes an interdigital electrode transducer and reflectors at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer on a $LiTaO_3$ substrate. A surface acoustic wave filter using the one-port surface acoustic wave resonator is required to have small fluctuation of frequency characteristics.

Patent Document 1 mentioned below discloses that good characteristics of one-port surface acoustic wave resonators using the above-mentioned Y-cut X-propagation $LiTaO_3$ substrate can be obtained by controlling the ratio (h/λ) of an electrode film thickness (h) to a wavelength (λ) of the surface acoustic wave to the range of 0.06 to 0.10 and by controlling the metallization ratio of the electrode to 0.6 or less.

Patent Document 2 mentioned below discloses that a yield of

ladder-type surface acoustic wave filters having a plurality of one-port surface acoustic wave resonators can be improved by controlling the metallization ratio of the electrode to 0.6 or more, preferably, to the range of 0.6 to 0.8.

The ladder-type surface acoustic wave filter having a plurality of one-port surface acoustic wave resonators is generally used in duplexers as a low-frequency bandpass filter. The ladder-type surface acoustic wave filter of the low-frequency bandpass filter is required to have steep cut-off characteristics at the blocking band of the higher frequency side of the pass band. Therefore, in order to increase the cut-off steepness, Q-factor of an antiresonance frequency is required to be improved in the one-port surface acoustic wave resonators constituting a serial arm resonator of a ladder circuit.

Additionally, it is known that the one-port surface acoustic wave resonator is serially connected to a surface acoustic wave filter in order to sufficiently increase attenuation level at a certain frequency in the outside of the pass band of the surface acoustic wave filter. Here, a trap is constituted at the antiresonance frequency of the one-port surface acoustic wave resonator. In such a structure, the Q-factor of the antiresonance frequency of the one-port surface acoustic wave resonator is also required to be improved.

Patent Document 3 mentioned below discloses that the Q-factor of the antiresonance frequency can be improved by controlling the cut angle of a rotated Y-cut X-propagation $LiTaO_3$ substrate to 46° or more in the one-port surface acoustic wave resonator using the $LiTaO_3$ substrate.

Non-Patent Document 1 mentioned below discloses that the Q-factor of the antiresonance frequency is increased by controlling the metallization ratio to less than 0.4 in the one-port surface acoustic wave resonator using a 36° to 42°-rotated Y-cut X-propagation $LiTaO_3$ substrate.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 7-283682

Patent Document 2: Japanese Unexamined Patent Application Publication No. 9-93072

Patent Document 3: US Patent No. 6,556,104

Non-Patent Document 1: T. Matsuda, J. Tsutsumi, S. Inoue, Y. Iwamoto, Y. Satoh, "High-Frequency SAW Duplexer with Low-Loss and Steep Cut-Off Characteristics" IEEE International Ultrasonics Symposium, Oct. 8-11, 2002

Disclosure of Invention

In a one-port surface acoustic wave resonator using a rotated Y-cut X-propagation $LiTaO_3$ substrate, the dependency of acoustic velocity on the metallization ratio is the lowest at a metallization ratio of about 0.75. Namely, when the metallization ratio is about 0.75, the frequency fluctuation caused by a fluctuation in the precision of electrode formation is the lowest. Therefore, as described in the Patent Documents 1 and 2, it is recognized that a metallization ratio of 0.6 or more is preferable for decreasing the frequency fluctuation and improving the yield.

According to the Patent Document 3, in the one-port surface acoustic wave resonator using a rotated Y-cut X-propagation $LiTaO_3$ substrate, the Q-factor of the antiresonance frequency can be improved by using the $LiTaO_3$ substrate having a cut angle of 46° or more. However, the Q-factor of the antiresonance frequency is sharply deteriorated with an increase in the metallization ratio of electrode, even if the one-port surface acoustic wave resonator using a 46° to 50°-rotated Y-cut $LiTaO_3$ substrate is prepared; which is a problem.

According to the Non-Patent Document 1, a favorable Q-factor of the antiresonance frequency is achieved by decreasing the

metallization ratio to 0.4 or less.

Therefore, in the one-port surface acoustic wave resonator using a Y-cut X-propagation $LiTaO_3$ substrate, the metallization ratio of the electrode must be increased to 0.5 or more in order to decrease the frequency fluctuation. On the other hand, a duty ratio must be decreased to 0.4 or less in order to improve the Q-factor of the antiresonance frequency. Thus, simultaneous realization of both the improvement of the Q-factor of the antiresonance frequency and the improvement of the frequency fluctuation is very difficult.

The present invention has been accomplished under such circumstances of the above-mentioned conventional technology, and an object of the present invention is to provide a one-port surface acoustic wave resonator having a Y-cut X-propagation $LiTaO_3$ substrate and being able to simultaneously realize both the improvement of the Q-factor of the antiresonance frequency and the decrease of the frequency fluctuation, and to provide a surface acoustic wave filter using the one-port surface acoustic wave resonator.

The one-port surface acoustic wave resonator according to a broad aspect of the present invention includes a rotated Y-cut $LiTaO_3$ substrate, an interdigital electrode transducer on the $LiTaO_3$ substrate, and reflectors at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer. When the electrode finger width of the interdigital electrode transducer is denoted by a and the gap between the electrode fingers is denoted by b, the metallization ratio, $a/(a + b)$, is in the range of 0.55 to 0.85 and the interdigital electrode transducer is assigned with overlapping-length weight.

In the present invention, the above-mentioned $LiTaO_3$ substrate preferably has a cut angle of 36° to 60°. In the one-port surface acoustic wave resonator including a rotated Y-cut $LiTaO_3$ substrate, an interdigital electrode transducer on the $LiTaO_3$ substrate, and

reflectors at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer, the metallization ratio, a/(a + b), is in the range of 0.45 to 0.85 when the electrode finger width of the interdigital electrode transducer is denoted by a and the gap between the electrode fingers is denoted by b, the interdigital electrode transducer is assigned with weight, and the cut angle of the $LiTaO_3$ substrate is in the range of 40° to 60°. Additionally, in the one-port surface acoustic wave resonator according to a specific aspect of the present invention, the amount of the overlapping-length weight is 87.5% or less, preferably 75% or less.

In the one-port surface acoustic wave resonator according to another specific aspect of the present invention, the film thickness of the interdigital electrode transducer is controlled so that the mass is equivalent to that of an aluminum electrode having a film thickness of 8 to 14% of the wavelength of the surface acoustic wave, preferably 8.5 to 11.5%, more preferably 9 to 11%.

In the one-port surface acoustic wave resonator according to another specific aspect of the present invention, the film thickness of the interdigital electrode transducer is controlled so that the mass is equivalent to that of a copper electrode having a film thickness of 2.4 to 4.2% of the wavelength of the surface acoustic wave.

In the one-port surface acoustic wave resonator according to another specific aspect of the present invention, the film thickness of the interdigital electrode transducer is controlled so that the mass is equivalent to that of a gold electrode having a film thickness of 1.1 to 2.0% of the wavelength of the surface acoustic wave.

The surface acoustic wave filter according to the present invention is constituted by using the one-port surface acoustic wave resonator according to the present invention. Examples of the surface acoustic wave filter include, but not limited to, a ladder-type

surface acoustic wave filter, a lattice-type surface acoustic wave filter, and a surface acoustic wave filter having a one-port surface acoustic wave resonator as a trap.

In the one-port surface acoustic wave resonator according to the present invention, an interdigital electrode transducer and a pair of reflectors are disposed on a rotated Y-cut $LiTaO_3$ substrate and the metallization ratio of the interdigital electrode transducer and the pair of reflectors is in the range of 0.55 to 0.85. Consequently, the frequency fluctuation can be effectively decreased. Additionally, since the interdigital electrode transducer is assigned with overlapping-length weight, not only the frequency fluctuation can be decreased, but also the Q-factor of the antiresonance frequency can be effectively increased.

Namely, in the one-port surface acoustic wave resonator, it has been very difficult to simultaneously achieve both a decrease in the frequency fluctuation and an improvement in the Q-factor of the antiresonance frequency. However, according to the present invention, the decrease in the frequency fluctuation and the improvement in the Q-factor of the antiresonance frequency can be simultaneously achieved by controlling the metallization ratio of the electrode in the above-mentioned particular range and assigning overlapping-length weight to the interdigital electrode transducer.

Therefore, cut-off steepness in the filter characteristics from the pass band to the blocking band can be increased and the control of the trap using the one-port surface acoustic wave resonator can be effectively improved by constituting various surface acoustic wave filters using the one-port surface acoustic wave resonator according to the present invention.

In particular, when the cut angle of the $LiTaO_3$ substrate is in the range of 36° to 60°, the Q-factor of the antiresonance frequency can be effectively improved. In the one-port surface acoustic wave

resonator including a rotated Y-cut $LiTaO_3$ substrate, an interdigital electrode transducer on the $LiTaO_3$ substrate, and reflectors at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer, the frequency fluctuation can be effectively decreased by controlling the metallization ratio, $a/(a + b)$, to the range of 0.45 to 0.85 when the electrode finger width of the interdigital electrode transducer is denoted by a and a gap between the electrode fingers is denoted by b, assigning weight to the interdigital electrode transducer, and also controlling the cut angle of the $LiTaO_3$ substrate to the range of 40° to 60°. Additionally, since the interdigital electrode transducer is applied with overlapping-length weight, not only the frequency fluctuation is decreased, but also the Q-factor of the antiresonance frequency can be effectively increased.

The Q-factor of the antiresonance frequency can be further effectively improved by controlling the amount of the overlapping-length weight to 87.5% or less, more preferably to 75% or less.

When the electrode film thickness is controlled so that the mass is equivalent to that of an aluminum electrode having a film thickness of 8 to 14% of the wavelength of the surface acoustic wave, the Q-factor of the antiresonance can be further effectively improved.

Similarly, when the electrode film thickness is controlled so that the mass is equivalent to that of an copper electrode having a film thickness of 2.4 to 4.2% of the wavelength of the surface acoustic wave, the Q-factor of the antiresonance frequency can be further effectively improved.

Similarly, when the electrode film thickness is controlled so that the mass is equivalent to that of a gold electrode having a film thickness of 1.1 to 2.0% of the wavelength of the surface acoustic wave, the Q-factor of the antiresonance frequency can be further effectively improved.

The surface acoustic wave filter according to the present invention is constituted by using the one-port surface acoustic wave resonator according to the present invention, therefore, the frequency fluctuation can be decreased and the Q-factor of the antiresonance frequency of the one-port surface acoustic wave resonator can be also improved. Consequently, cut-off steepness of the filter characteristics from the pass band to the blocking band of the surface acoustic wave filter can be increased and the trap characteristics can be effectively improved by using the one-port surface acoustic wave resonator as the trap.

Brief Description of the Drawings

[FIG. 1] In FIG. 1, (a) is a plan view of a one-port surface acoustic wave resonator according to an embodiment of the present invention, and (b) is an enlarged view of the substantial part.

[FIG. 2] FIG. 2 is a graph showing the relationship between the metallization ratio of the electrode and resonance frequency in the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer in Example 1.

[FIG. 3] FIG. 3 is a graph showing the relationship between the metallization ratio of the electrode and frequency fluctuation in the surface acoustic wave resonator having a normal-type interdigital electrode transducer in Example 1.

[FIG. 4] FIG. 4 is a graph showing the relationship between the metallization ratios and the Q-factors of the antiresonance frequency in a comparative example of the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer and in three examples of the one-port surface acoustic wave resonator which are assigned with overlapping-length weight.

[FIG. 5] FIG. 5 is a graph schematically showing impedance-frequency characteristics and phase-frequency characteristics when the

metallization ratio of the electrode is varied in the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer.

[FIG. 6] FIG. 6 is a graph showing the relationship among the cut angle and the duty ratio of the $LiTaO_3$ substrate and the Q-factor of the antiresonance frequency, in the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer.

[FIG. 7] FIG. 7 is a graph showing the relationship between the metallization ratio of the electrode and the Q-factor of the antiresonance frequency in the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer.

[FIG. 8] FIG. 8 is a graph showing the relationship between the metallization ratio of the electrode and the Q-factor of the antiresonance frequency when an aluminum film is further deposited on the busbar of the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer.

[FIG. 9] FIG. 9 is a graph schematically showing impedance-frequency characteristics and phase-frequency characteristics in a comparative example of the one-port surface acoustic wave resonator having a normal-type interdigital electrode transducer and in three examples of the one-port surface acoustic wave resonator which are assigned with overlapping-length weight at an amount of 67.5%, 75%, or 87.5%.

[FIG. 10] FIG. 10 is a graph showing the relationship between the aluminum-electrode film thickness and the Q-factor of the antiresonance frequency in an example of the one-port surface acoustic wave resonator having interdigital electrode transducer assigned with overlapping-length weight.

[FIG. 11] FIG. 11 is a graph showing the relationship between the cut angle of an aluminum substrate and the Q-factor of the antiresonance frequency in an example of the one-port surface acoustic

wave resonator having interdigital electrode transducer assigned with overlapping-length weight.

[FIG. 12] FIG. 12 is a plan view showing an electrode structure of a surface acoustic wave filter having a ladder circuit structure as an example of the surface acoustic wave filter according to the present invention.

[FIG. 13] FIG. 13 is a plan view showing an electrode structure of a surface acoustic wave filter having a lattice circuit structure as another example of the surface acoustic wave filter according to the present invention.

[FIG. 14] FIG. 14 is a plan view showing an electrode structure of a surface acoustic wave filter having a trap as another example of the surface acoustic wave filter according to the present invention.

Reference Numerals

1 one-port surface acoustic wave resonator

2 $LiTaO_3$ substrate

3 interdigital electrode transducer

3a electrode finger

4, 5 reflector

4a, 4b electrode finger

31 ladder-type surface acoustic wave filter

41 lattice-type surface acoustic wave filter

42 to 45 one-port surface acoustic wave resonator

51 surface acoustic wave filter having a trap

52 surface acoustic wave filter portion

53 one-port surface acoustic wave resonator

S1, S2 serial arm resonator

P1 to P3 parallel arm resonator

Best Mode for Carrying Out the Invention

The present invention will now be clarified by specifically describing embodiments with reference to the drawings.

FIG. 1(a) is a schematic plan view showing a one-port surface acoustic wave resonator according to an embodiment of the present invention, and b is an enlarged view of the substantial part. The one-port surface acoustic wave resonator 1 includes a rotated Y-cut X-propagation $LiTaO_3$ substrate 2. The cut angle of the $LiTaO_3$ substrate is preferably in the range of 36° to 60°, as it is obvious from Examples mentioned below.

On the $LiTaO_3$ substrate, an interdigital electrode transducer 3 and reflectors 4 and 5 at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer 3 are disposed. The interdigital electrode transducer 3 and the reflectors 4 and 5 are formed by depositing a metal material such as aluminum or an aluminum-based alloy on the $LiTaO_3$ substrate and then patterning it. Metal materials other than aluminum and the aluminum-based alloy can be also used as the metal material.

The interdigital electrode transducer 3 includes a plurality of electrode fingers 3a intercalating into each other. Each of the reflectors 4 and 5 has a plurality of electrode fingers 4a and 5a, respectively, and has a structure that both ends are each connected to the other side.

In the one-port surface acoustic wave resonator 1 according to this embodiment, the interdigital electrode transducer 3 and the reflectors 4 and 5 have a metallization ratio, $a/(a + b)$, of 0.55 to 0.85, and the interdigital electrode transducer 3 is assigned with overlapping-length weight as shown in the drawing. As shown in FIG. 1(b), the metallization ratio, $a/(a + b)$, is a ratio of an electrode finger width a to the total of the electrode finger width a and a gap b between the electrode fingers, when the electrode finger width of the interdigital electrode transducer 3 is denoted by a and the gap

between the electrode fingers is denoted by b.

In this embodiment, as shown in FIG. 1(a), the overlapping-length weight assigned to the interdigital electrode transducer 3 is conducted by determining the length of a plurality of the electrode fingers 3a in such a manner that the overlapping-length is the longest at the center and is reduced toward the outside in the surface acoustic wave propagation direction. FIG. 1(a) shows an example of the assignment of overlapping-length weight. In FIG. 1(a), the overlapping-length at both sides in the surface acoustic wave propagation direction of the interdigital electrode transducer 3 is drawn in a very small size compared with the overlapping-length at the center, in order to clearly show the overlapping-length weight is assigned. In the present invention, the overlapping-length for assigning weight is determined so that the amount of the assigned weight is preferably 87.5% or less, more preferably, 75% or less. With this, the Q-factor of the antiresonance frequency can be effectively improved. As shown in FIG. 1(a) by broken lines, the areas where the electrodes are removed for assigning weight may be provided with dummy electrodes 6.

The amount of the overlapping-length weight stands for the degree of the assignment of overlapping-length weight. For example, when an envelope curve defined by joining the ends of the electrode fingers providing for the overlapping length is linear as the interdigital electrode transducer 3 shown in FIG. 1(a), the amount of the overlapping-length weight is represented by $(B/A) \times 100$ (%), wherein A means the maximum extent of the overlapping length at the center of the interdigital electrode transducer 3 and B means the minimum extent of the overlapping length at both ends in the surface acoustic wave propagation direction of the interdigital electrode transducer 3.

The envelope curve is a virtual line providing for the outer edge of the overlapping-length area. For example, in the interdigital

electrode transducer 3, the envelope curve is a line joining the ends of a plurality of the electrode fingers which are connected to each other at the same electric potential.

As mentioned above, when the overlapping-length weight is assigned so that the envelope curve is linear, the amount of the overlapping-length weight is represented by $(B/A) \times 100$ (%). In the present invention, the overlapping-length weight may be assigned so that the envelope curve has a shape, such as a sine curve, other than a line. When the overlapping-length weight is assigned in such a manner that the envelope curve has a shape other than a line, the dimensions of the area where the overlapping-length weight is assigned is determined on the basis of dimensions of an area where the overlapping-length weight is supposed to be assigned in such a manner that the envelope curve is linear. Namely, when the dimensions of the area where the weight is assigned in such a manner that the envelope curve has a shape other than a line is Y, the dimensions of the area where the weight is supposed to be assigned in such a manner that the envelope curve has a line is Y and the $(B/A) \times 100$ (%) is Z; the amount of the overlapping-length weight in the case that the envelope curve has the shape other than a line can be Z.

In the one-port surface acoustic wave resonator 1, the interdigital electrode transducer 3 and the reflectors 4 and 5 are formed on the $LiTaO_3$ substrate in such a manner that the metallization ratio is in the range of 0.45 to 0.85. Therefore, as it is obvious from examples, the antiresonance frequency fluctuation caused by a fluctuation in the electrode precision can be effectively decreased.

Additionally, the Q-factor of the antiresonance frequency can be significantly improved since the interdigital electrode transducer 3 is assigned with overlapping-length weight. This will be described with reference to the following concrete examples.

(Example 1)

Rotated Y-cut X-propagation $LiTaO_3$ substrates were prepared. A normal-type interdigital electrode transducer and a pair of reflectors were formed with aluminum on each of the $LiTaO_3$ substrate at various metallization ratios. Then, resonance frequencies were determined. FIG. 2 shows the results. The wavelength of the interdigital electrode transducer 3 was adjusted to about 2 μm. The target resonance frequency was a resonance frequency of 2 GHz, and the electrode film thickness was 10% of the wavelength. With reference to FIG. 2, it was confirmed that the resonance frequency varied with a change in the metallization ratio of the interdigital electrode transducer and the reflectors. It was also observed that the resonance frequency was the lowest at a metallization ratio of about 0.7.

One-port surface acoustic wave resonators having various metallization ratios were prepared by the same manner as in the above. Resonance frequency fluctuation was determined when the size fluctuation in the width direction of the electrode fingers was ± 0.02 μm. FIG. 3 shows the results.

The frequency fluctuation on the vertical axis in FIG. 3 is a ratio (ppm) of a difference between an actual value of resonance frequency of the prepared surface acoustic wave resonator and a target resonance frequency of 2 GHz to the target resonance frequency of 2 GHz.

With reference to FIG. 3, it was observed that the frequency fluctuation was the lowest at a metallization ratio of about 0.7.

A frequency fluctuation of 4000 ppm or less is preferable for the use in which smaller frequency tolerance is required. With reference to FIG. 3, it was observed that the requirement could be satisfied by controlling the metallization ratio to the range of 0.55 to 0.85.

The inventors confirmed that the preferable range of the metallization ratio shown in FIG. 3 did not depend on the electrode

film thickness, from the results of an experiment performed by using aluminum electrodes having various film thicknesses.

(Example 2)

One-port surface acoustic wave resonator having a normal-type interdigital electrode transducer and a pair of reflectors were prepared as in Example 1. In this time, a Y-cut X-propagation $LiTaO_3$ substrate had a cut angle of 46°, the wavelength was about 2 μm, the film thickness of the interdigital electrode transducer and the reflectors were 10% of the wavelength, the number of electrode finger pairs of the interdigital electrode transducer was 125, the overlapping-length of the electrode fingers was 32 μm, and the target resonance frequency was about 2 GHz. The metallization ratios of the one-port surface acoustic wave resonators were varied, and Q-factors of the antiresonance frequency were determined. The results were shown in FIG. 4 by a solid line C. FIG. 5 shows impedance-frequency characteristics and phase-frequency characteristics.

As it is obvious from the solid line C in FIG. 4 and the wave patterns in FIG. 5, in the area where the metallization ratio is higher than 0.45, it is observed that the Q-factor of the antiresonance frequency is significantly decreased to 800 or less. On the other hand, it is observed that the Q-factor is favorably 600 or more when the metallization ratio is 0.45 or less. This tendency agrees with the content described in the above-mentioned Non-Patent Document 1.

Therefore, in view of the results of Example 1 and Example 2, it is observed that the frequency fluctuation exceeds 7000 ppm in the conventional one-port surface acoustic wave resonator, even if the metallization ratio is controlled to 0.4 in order to obtain a good Q-factor of the antiresonance frequency. This frequency fluctuation is 14 MHz if the resonance frequency is 2 GHz. Therefore, this frequency fluctuation is a crucial defect in a device, such as a mobile phone,

having a narrow frequency difference of 20 MHz between a transmit band and a receive band. Additionally, it is also highly required in other applications to decrease such a large frequency fluctuation.

However, as it was confirmed in Examples 1 and 2, it has been very difficult to simultaneously achieve both a decrease in the frequency fluctuation and a good Q-factor of the antiresonance frequency.

(Example 3)

In a rotated Y-cut X-propagation $LiTaO_3$ substrate, as described in the above-mentioned Patent Document 3, the Q-factor of the antiresonance frequency can be improved by controlling the cut angle of the $LiTaO_3$ substrate in the range of 46° to 54°. Then, two types of one-port surface acoustic wave resonators having a metallization ratio of 0.4 or 0.6 were prepared by using Y-cut $LiTaO_3$ substrates having various cut angles, as in Example 2. FIG. 6 shows the relationship between the cut angles of the $LiTaO_3$ substrates in the resulting surface acoustic wave resonators and Q-factors of the antiresonance frequency.

As it is obvious from FIG. 6, when the metallization ratio was 0.4, the Q-factor of the antiresonance frequency was sharply improved with an increase in the cut angle. On the other hand, when the metallization ratio was 0.6, the Q-factor of the antiresonance frequency was hardly improved even if the cut angle was increased.

As it is obvious from Example 3, the Q-factor of the antiresonance frequency cannot be improved because of the cut angle characteristics even if the metallization ratio is controlled to 0.6 for improving the frequency fluctuation.

(Example 4)

In the above-mentioned Non-Patent Document 1, the Q-factor of the antiresonance frequency is improved by decreasing the metallization ratio of electrodes. The cause of this is thought to be due to the waveguiding effect. Namely, the acoustic velocity at the surface

acoustic wave propagation part of the interdigital electrode transducer is sufficiently faster than that at a busbar when the metallization ratio is small. Consequently, the locked-in effect of the interdigital electrode transducer as the waveguide is improved. Thus, it has been thought that the leakage of the surface acoustic wave from the busbar to the outside of the resonator is decreased to improve the Q-factor of the antiresonance frequency.

Therefore, if the above-mentioned cause is correct, it is thought that the Q-factor may be improved by decreasing the acoustic velocity at the busbar instead of increasing the acoustic velocity in the interdigital electrode transducer. Therefore, an aluminum film having a thickness of about 1 μm was deposited on only the busbar of each of the surface acoustic wave resonators having electrodes of various metallization ratios as in Example 2. FIG. 7 shows the relationship between the Q-factor of the antiresonance frequency and the metallization ratio of the surface acoustic wave resonator before the deposition of the second layer of the aluminum film having a thickness of about 1 μm on the busbar. The results shown in FIG. 7 are the same as the solid line C in the above-mentioned FIG. 4.

FIG. 8 shows the relationship between the Q-factor of the antiresonance frequency and the metallization ratio of the surface acoustic wave resonator after the deposition of the second layer of the aluminum film on the busbar. As it is obvious by comparison of FIG. 7 and FIG. 8, it is observed that the Q-factor of the antiresonance frequency is hardly improved, even if the acoustic velocity of the busbar is lowered. Namely, it is understood that the improvement of the Q-factor of the antiresonance frequency by controlling the relationship between the acoustic velocity at the busbar and the acoustic velocity at the interdigital electrode transducer is difficult.

(Example 5)

From the results of Examples 3 and 4, it is not thought that the main causes of the deterioration in the Q-factor of the antiresonance frequency when the metallization ratio is large are leakage components of the surface acoustic wave to the inside of the substrate and leakage components of the surface acoustic wave to the outside from the busbar. Furthermore, it was confirmed that the Q-factor of the antiresonance frequency was not improved by increasing the number of the reflector. Namely, it is not thought that the cause is the leakage of the surface acoustic wave due to shortage of the reflector.

The inventors have extensively studied and found that the Q-factor of the antiresonance frequency can be improved by assigning weight, in particular, by assigning overlapping-length weight to the interdigital electrode transducer 3.

In Example 5, the one-port surface acoustic wave resonators were prepared as in Example 2 except that the interdigital electrode transducers were assigned with overlapping-length weight. In this case, various types of the one-port surface acoustic wave resonators were prepared by varying the above-mentioned amounts of the overlapping-length weight. The metallization ratio of the electrodes was 0.6.

FIG. 9 shows the results. FIG. 9 is graphs arranging vertically impedance-frequency characteristics and phase-frequency characteristics of various types of one-port surface acoustic wave resonators thus prepared. FIG. 9 shows one-port surface acoustic wave resonator characteristics of a comparative example in which a normal-type interdigital electrode transducer is used and of three types of examples in which the amount of the weight of 87.5%, 75%, or 67.5% is assigned. In FIG. 9, the frequency characteristics of the various types of surface acoustic wave resonators are slightly shifted for ease of understanding. Therefore, each characteristic is separately illustrated.

The Q-factors of the antiresonance frequency were determined by variously changing the metallization ratio of electrodes in the plurality of one-port surface acoustic wave resonators assigned with overlapping-length weight. The results are shown in the above-mentioned FIG. 4 by solid lines O, X, and Δ. In FIG. 4, O, X, and Δ show the results when the amounts of the overlapping-length weight were 87.5%, 75%, and 67.5%, respectively.

As it is obvious from FIG. 4 and FIG. 9, it is observed that the Q-factor of the antiresonance frequency is sharply improved by assigning overlapping-length weight to the interdigital electrode transducer. Additionally, as it is obvious from FIG. 9, the resonance characteristics themselves were not largely changed even if the above-mentioned overlapping-length weight was assigned. Therefore, it is understood that both the decrease in the frequency fluctuation and the improvement in Q-factor of the antiresonance can be simultaneously achieved by assigning overlapping-length weight to the interdigital electrode transducer, even if the metallization ratio was large such as 0.45 or more. In particular, the Q-factor of the antiresonance frequency can be effectively improved by assigning overlapping-length weight, preferably an overlapping-length weight of 75% or less, more preferably, 87.5% or less when the metallization ratio is in the range of 0.55 to 0.85, in which the frequency fluctuation can be effectively improved.

(Example 6)

As it is obvious from Example 5, even if the metallization ratio is large such as in the range of 0.45 to 0.85, the Q-factor of the antiresonance frequency can be effectively improved by assigning overlapping-length weight to the interdigital electrode transducer. Then, influences of the electrode film thickness on this effect were investigated. In the one-port surface acoustic wave resonators using a 48°-rotated $LiTaO_3$ substrate and being assigned with overlapping-

length weight at an amount of 75%, improvement ratios (%) of the Q-factor of the antiresonance frequency were determined by varying the electrode film thickness. The metallization ratio was 0.5. FIG. 10 shows the results.

As it is obvious from FIG. 10, it is observed that the Q-factor of the antiresonance frequency can be improved by assigning overlapping-length weight when the aluminum-electrode film thickness is in the range of 8 to 14% of a wavelength of the surface acoustic wave. In particular, the Q-factor is improved by 50% or more when the aluminum-electrode film thickness is in the range of 8.5 to 11.5% and is improved by 100% or more when the electrode film thickness is in the range of 9 to 11%.

Therefore, in the present invention, the range of the electrode film thickness is preferably 8 to 14% of the wavelength, more preferably 8.5% to 11.5%, further preferably 9 to 11%, when the electrode is made of aluminum.

Furthermore, when the electrode is made of a metal material other than aluminum such as copper or gold, or when the electrode is formed by laminating a plurality of metal materials, the similar effects could be obtained as long as the electrode has a thickness equivalent to the mass and the film thickness of the above-mentioned aluminum-electrode film thickness.

Namely, an aluminum-electrode film thickness of 8 to 14% of the wavelength is equivalent to a copper-electrode film thickness of 2.4 to 4.2% of the wavelength and is equivalent to a gold-electrode film thickness of 1.1 to 2.0% of the wavelength. Similarly, an aluminum-electrode film thickness of 8.5 to 11.5% or 9.0 to 11.0% of the wavelength is equivalent to a copper-electrode film thickness of 2.6 to 3.5% or 2.7 to 3.3%, respectively, and is equivalent to a gold-electrode film thickness of 1.2 to 1.6% or 1.3 to 1.5%, respectively.

(Example 7)

In Example 7, increase ratios of the Q-factor of the antiresonance frequency were determined by varying the cut angle of the $LiTaO_3$ substrate. The interdigital electrode transducers were the same as those in Example 6, and the aluminum-electrode film thickness was 10% of the wavelength of the surface acoustic wave. FIG. 11 shows the results.

As obvious from FIG. 11, according to the present invention, the Q-factor of the antiresonance frequency can be improved in all the cut angles of the $LiTaO_3$ substrate. In particular, when the cut angle is 40° to 60°, improvement effects on the Q-factor caused by using the interdigital electrode transducer assigned with overlapping-length weight was 100% or more compared with the case of using a normal-type interdigital electrode transducer. Furthermore, when the cut angle is 44° to 54°, the cut angle also improves the Q-factor of the antiresonance frequency. As a result, the Q-factor of the antiresonance frequency can be further effectively improved with the Q-factor-improvement effect by assigning overlapping-length weight to the interdigital electrode transducer. Therefore, a metallization ratio of 0.45 to 0.85 and a cut angle of 40° to 60° are preferable.

In the one-port surface acoustic wave resonator according to the present invention, both the frequency fluctuation and the Q-factor of the antiresonance frequency are simultaneously improved by controlling the metallization ratio to the range of 0.45 to 0.85, more preferably 0.55 to 0.85 and using interdigital electrode transducer assigned with overlapping-length weight. Therefore, cut-off steepness of the filter characteristics can be effectively improved by constituting a surface acoustic wave filter using the one-port surface acoustic wave resonator according to the present invention, or attenuation level of the blocking band of a surface acoustic wave filter can be effectively improved by using the one-port surface acoustic wave resonator as a trap. Examples of the one-port surface acoustic wave resonator

according to the present invention and the surface acoustic wave filter using it include, but not limited to, surface acoustic wave filters shown in FIGs. 12 to 14.

The surface acoustic wave filter shown in FIG. 12 is a ladder-type surface acoustic wave filter 31 and includes a plurality of serial arm resonators S1 and S2 and parallel arm resonators P1 to P3. The one-port surface acoustic wave resonator according to the present invention can be used as such a serial arm resonator or parallel arm resonator. In particular, the Q-factor of the antiresonance frequency in the serial arm resonators S1 and S2 can be improved by applying the one-port surface acoustic wave resonator according to the present invention to the serial arm resonators S1 and S2. With this, cut-off steepness in the filter characteristics can be increased at the higher frequency side of the pass band of the ladder-type surface acoustic wave filter 31.

The surface acoustic wave filter shown in FIG. 13 is a surface acoustic wave filter 41 in a lattice circuit arrangement, and a plurality of one-port surface acoustic wave resonators 42 to 45 are connected to each other so as to make grid connection. The one-port surface acoustic wave resonator according to the present invention can be suitably used as the one-port surface acoustic wave resonators 42 to 45.

FIG. 14 shows a surface acoustic wave filter 51 using a one-port surface acoustic wave resonator for constituting a trap. In the surface acoustic wave filter 51, the one-port surface acoustic wave resonator 53 is connected with a surface acoustic wave filter portion 52 to constitute the trap. Favorable trap characteristics can be obtained by utilizing the antiresonance frequency of the one-port surface acoustic wave resonator according to the present invention used as the one-port surface acoustic wave resonator 53.